Calibration and first user experience with the Large Pixel Detector at the European XFEL

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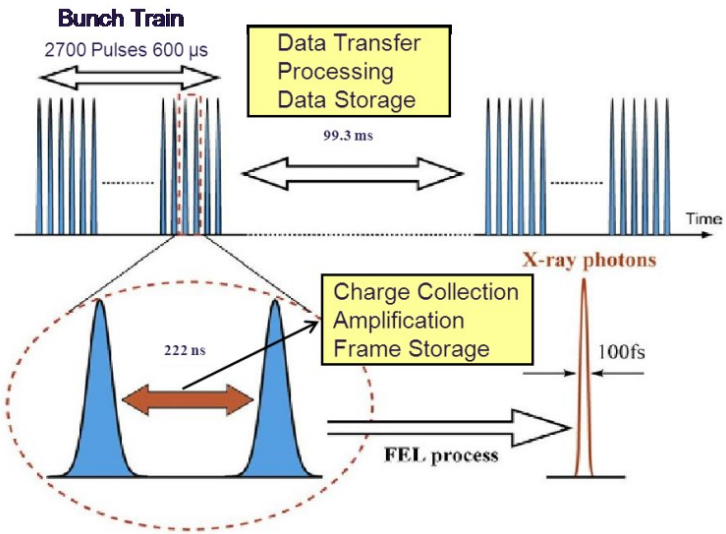
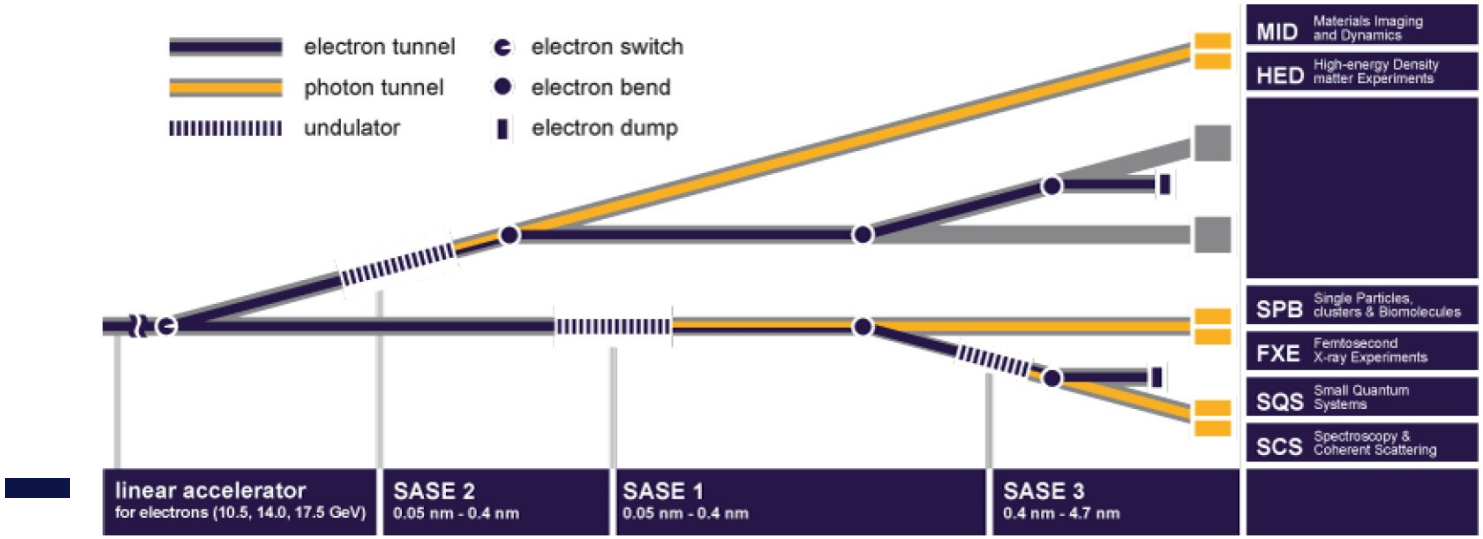
European XFEL GmbH, Detector Development
European XFEL GmbH, FXE Instrument
European XFEL GmbH, CAS
Rutherford Appleton Laboratory, STFC

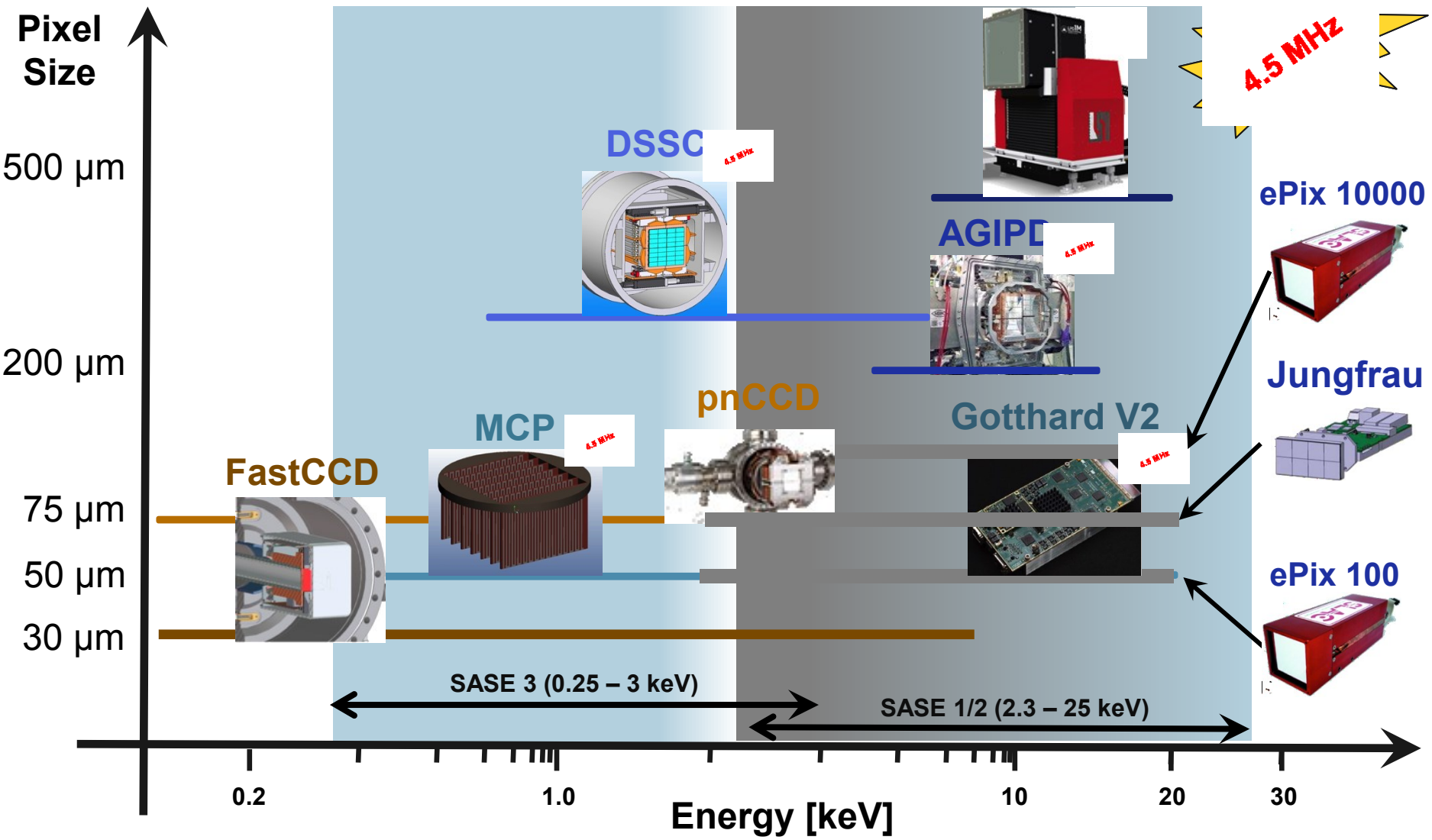
20th International Workshop on Radiation Imaging Detectors
Sundsvall, 28.6.2018

The European XFEL





Detectors for the European XFEL

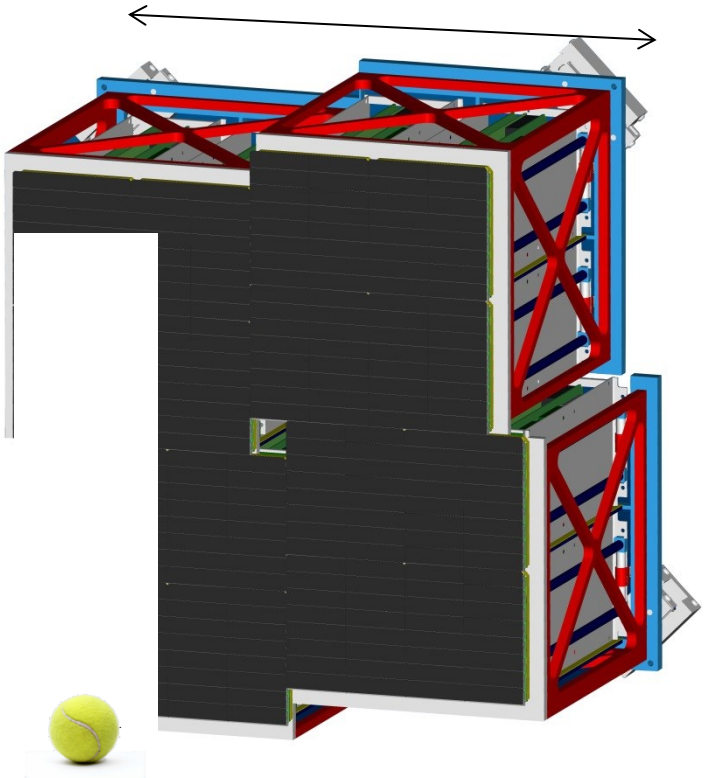


Overview

- The LPD 1M Setup at the FXE instrument
- Calibration Status
- First User Experience

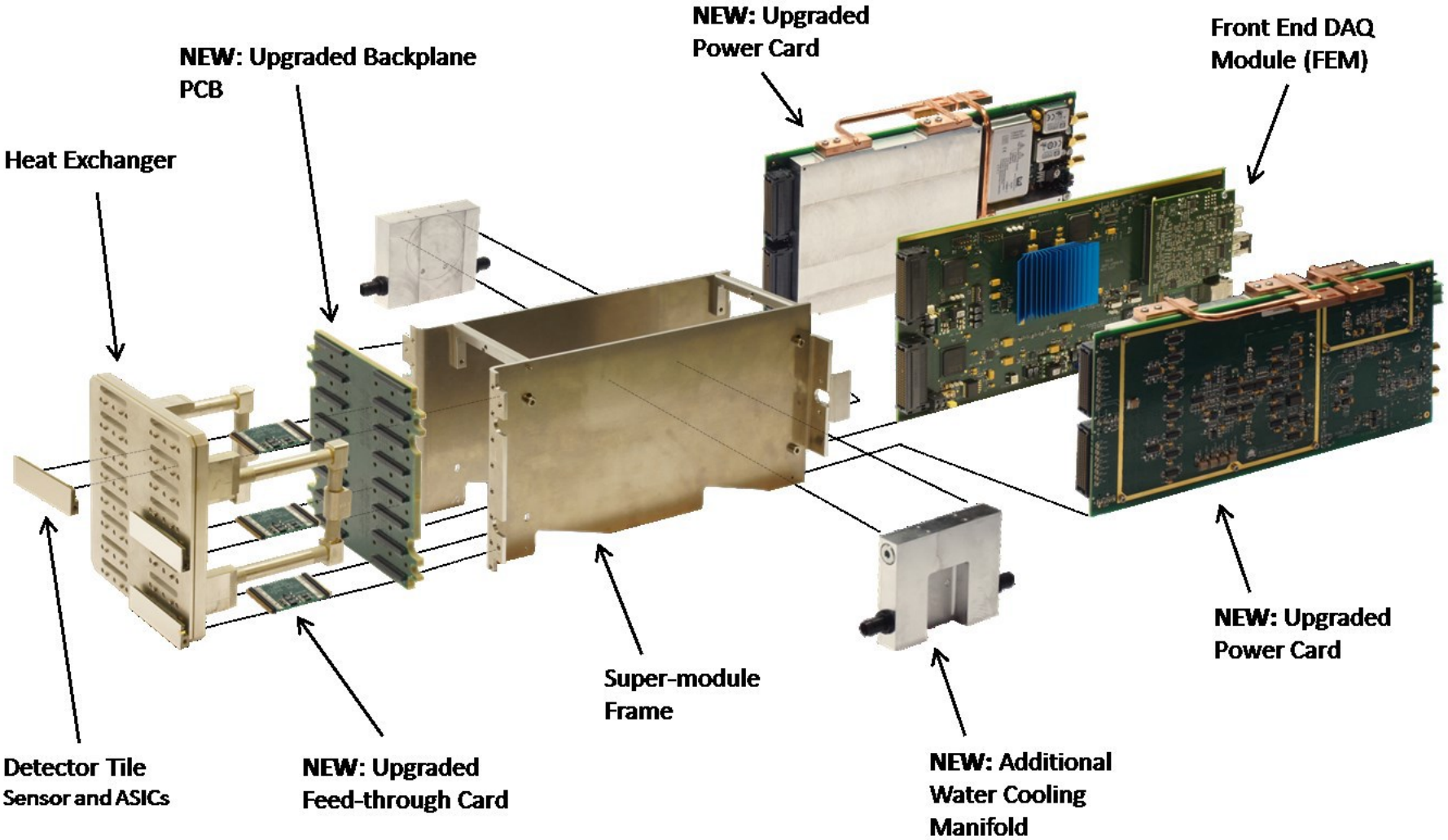
The LPD Detector

- Built by the Rutherford Appleton Laboratory for the European XFEL
  (Project Leaders: M. French, M. Hart)
- **Ambient operation** with photon energies **5-20keV**
- **1 Megapixel** - 500µm pixels
- **4.5MHz frame rate**
- **High dynamic range**, 1 to >10^4 photons per pixel per pulse. Using parallel gain stages (1x, 10x, 100x)
- **512(510) frame memory depth** continuously stores all three gains, overwriting whenever a veto is received
- Output data rate ~**10GByte/s** per Megapixel

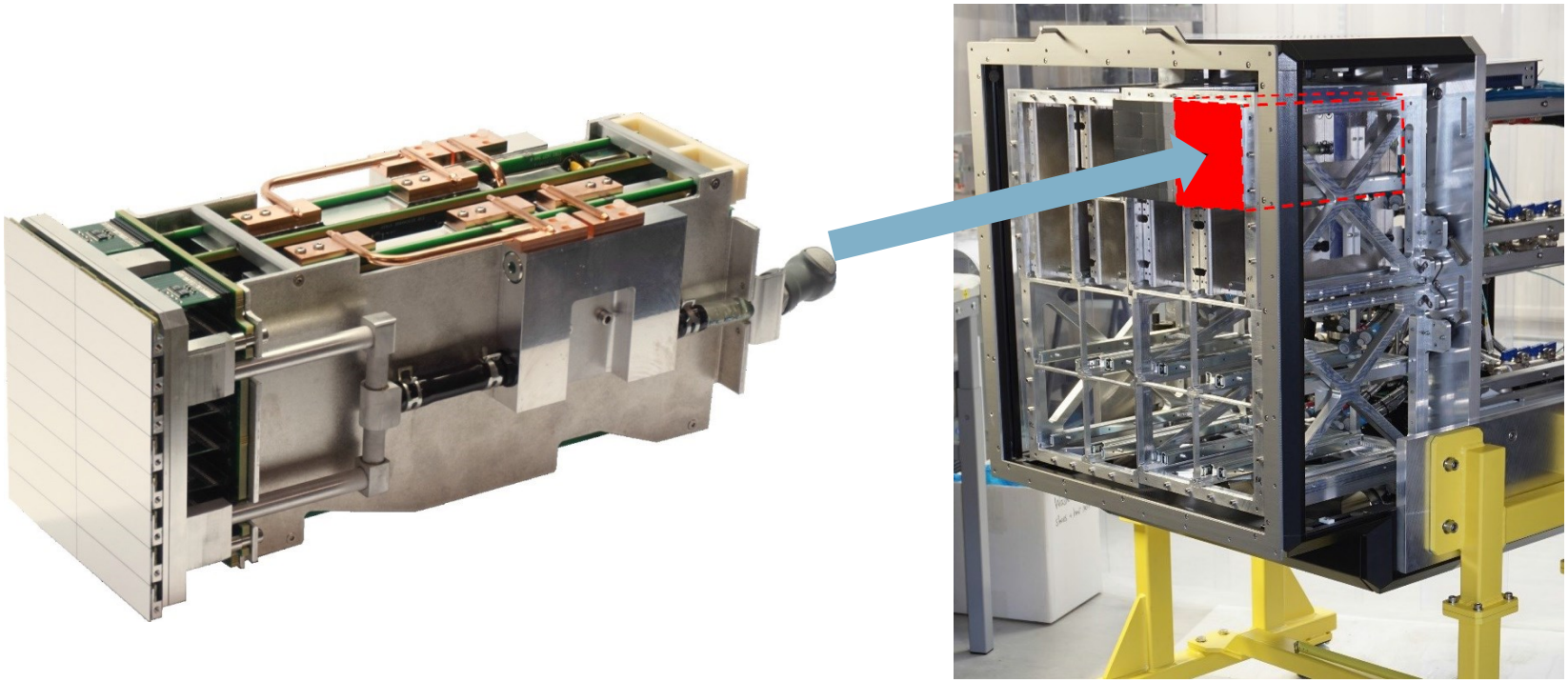


LPD Megapixel detector consists of:
- 16 Supermodules
- 256 Detector Tiles
- 2048 ASICs

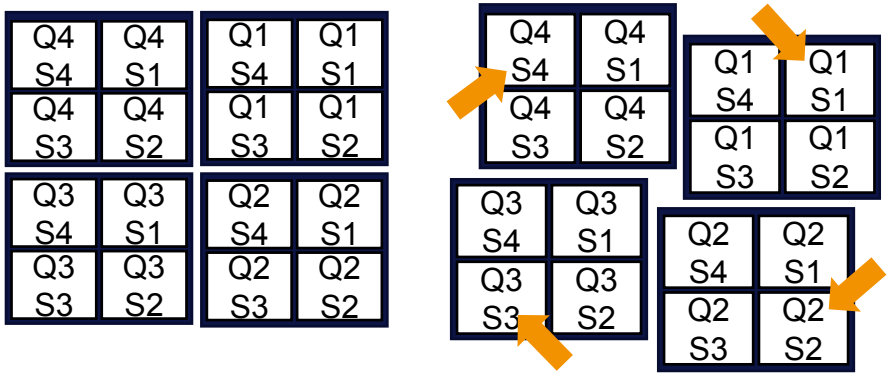
Components


NEW: Upgraded Power Card
Front End DAQ Module (FEM)
NEW: Upgraded Backplane PCB
Heat Exchanger
NEW: Upgraded Power Card
Super-module Frame
Detector Tile
Sensor and ASICs
NEW: Upgraded Feed-through Card
NEW: Additional Water Cooling Manifold

Components

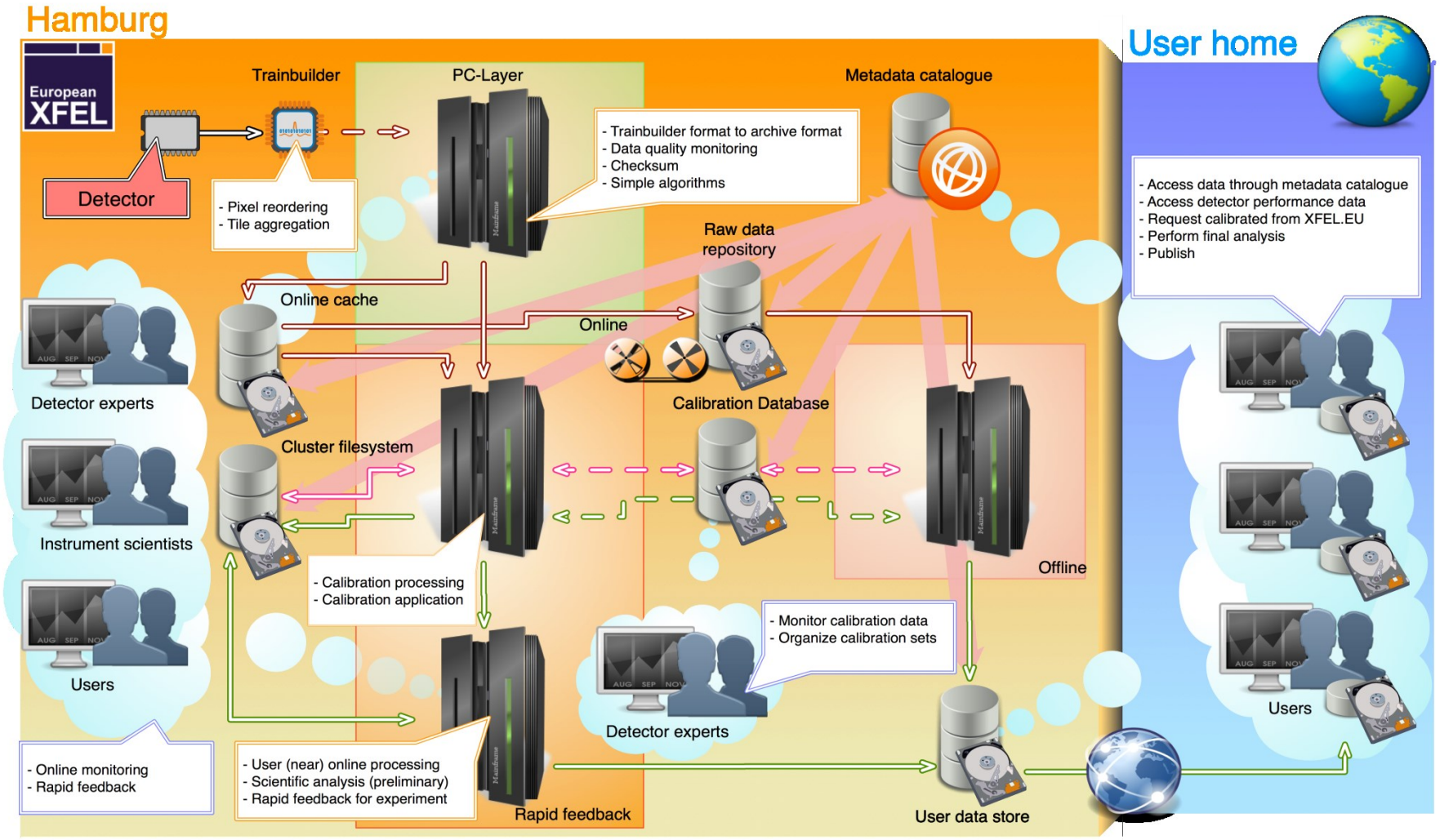


LPD at FXE and Quadrant Movement



- Beam pipes with diameter of 4mm and 10mm are provided by RAL (stainless steel w. carbon sheath)
- Max. opening diameter: 30mm
- Movement precision: 50 µm
- Special pipes can be provided on request

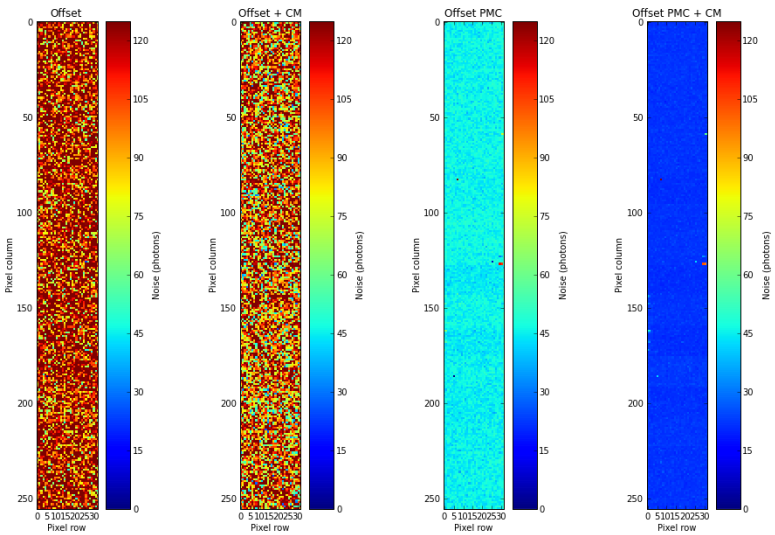
The Big Picture



Not shown is technical infrastructure such as switches.
Alignment datasets are shipped with the data products and tools for coordinate system conversion are provided by the facility.

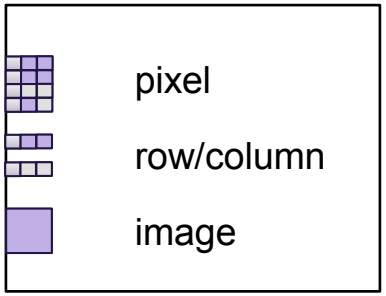
Calibration Pipeline - Example

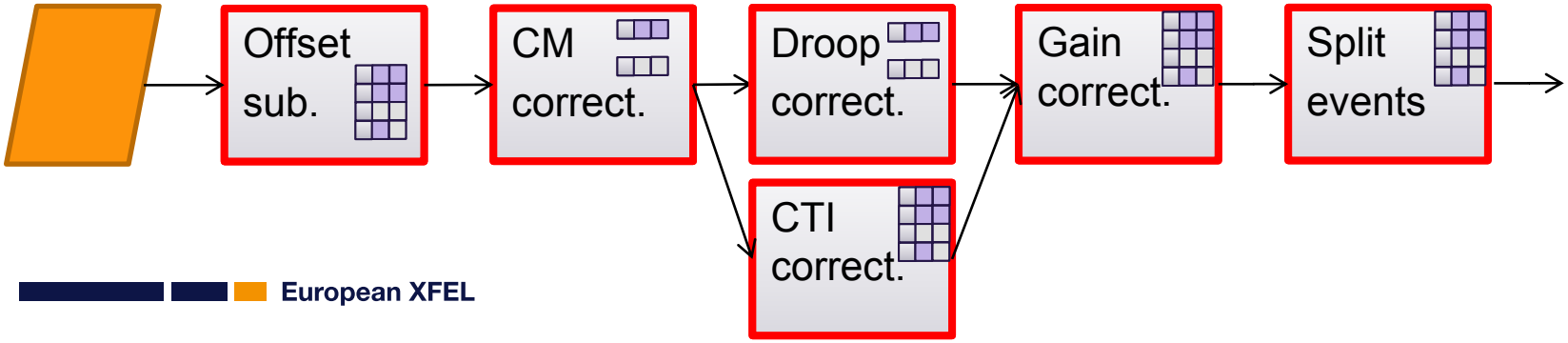
Example LPD: In terms of e.g. offset correction the LPD is 1.5 Gpixel detector:
1 Mpix x 512 memory cells x 3 gains
→ "Offset Map" has approx. 3 GB in size



~10^9 correction and calibration constants, evaluated for the correct detector operating conditions.

~ Gigabytes of calibration constants needed

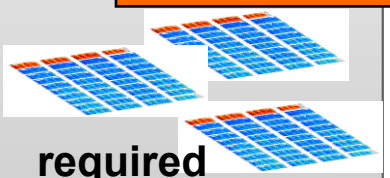




Calibration Catalogue

Observation with Det. X at Condition Y

Conditions



required constants

Condition Set 1: T = 20° C ± 1 ° C, V = 200V ± 5V, E = 12keV ± 0.1keV,

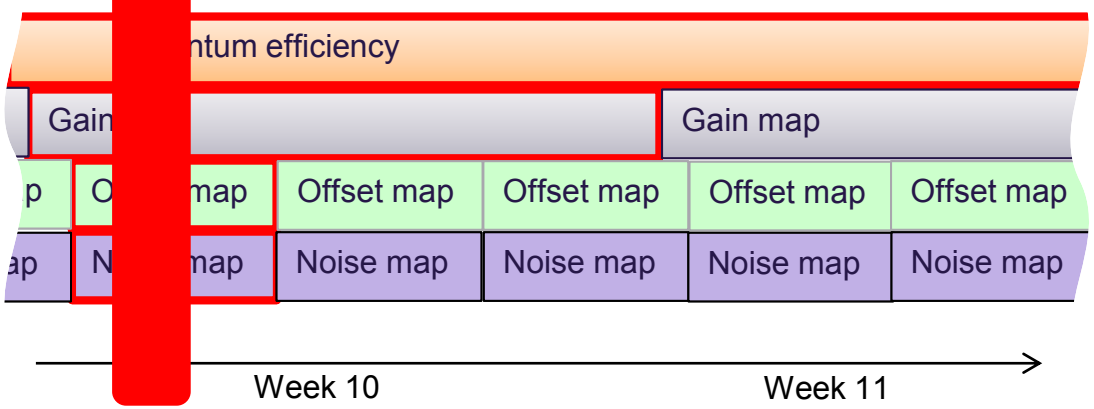
p = log(10^{-3}bar) ± 1log(bar) …

Condition Set 2: T = 25° C ± 1 ° C, V = 200V ± 5V, E = 18keV ± 0.1keV,

p = log(10^{-3}bar) ± 1log(bar) …

Condition Set n: T = **21**° C ± 1 ° C, V = **195V** ± 5V, E = 12keV ± 0.1keV,

p = log(10^{-3}bar) ± 1log(bar) …



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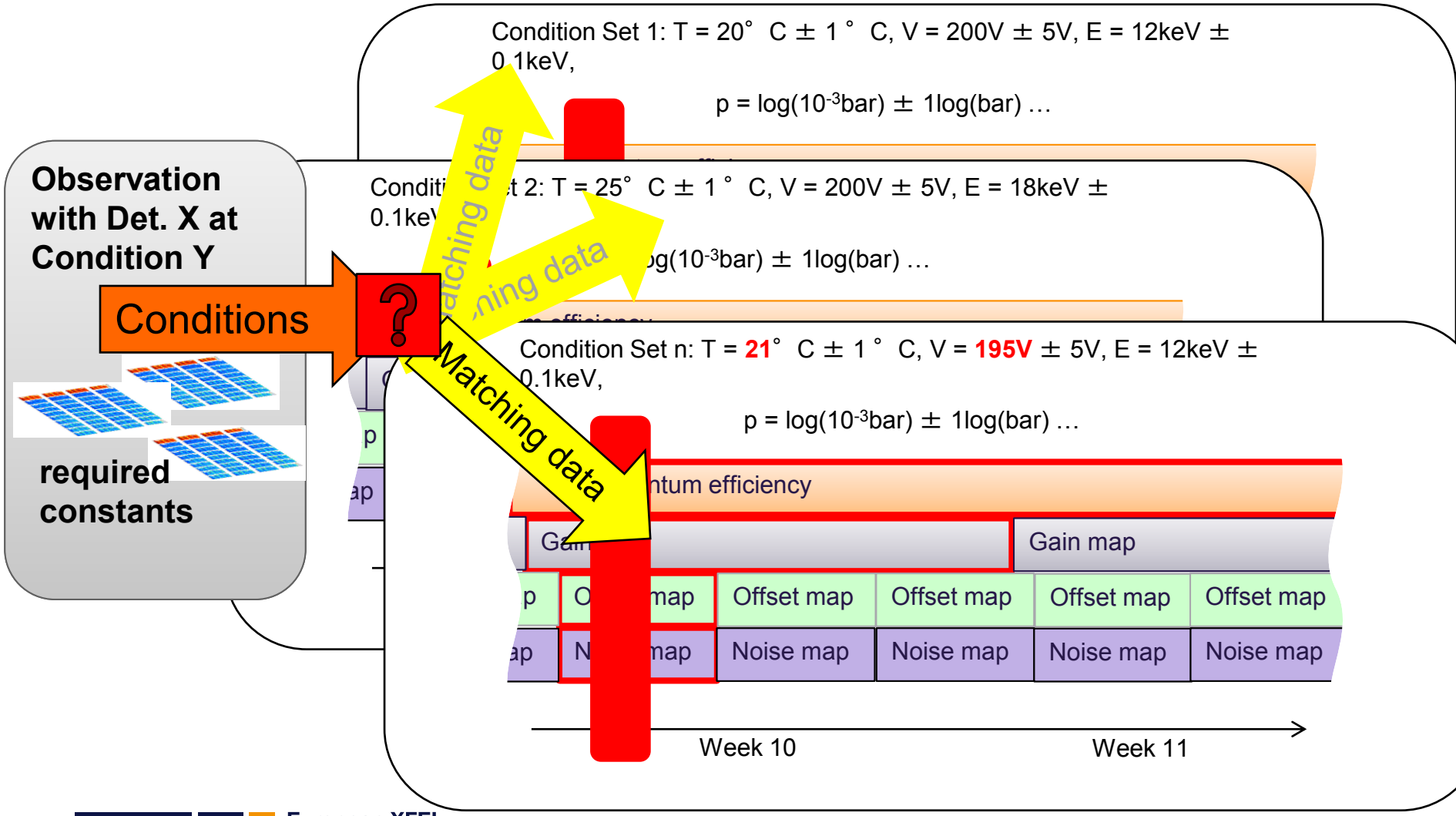

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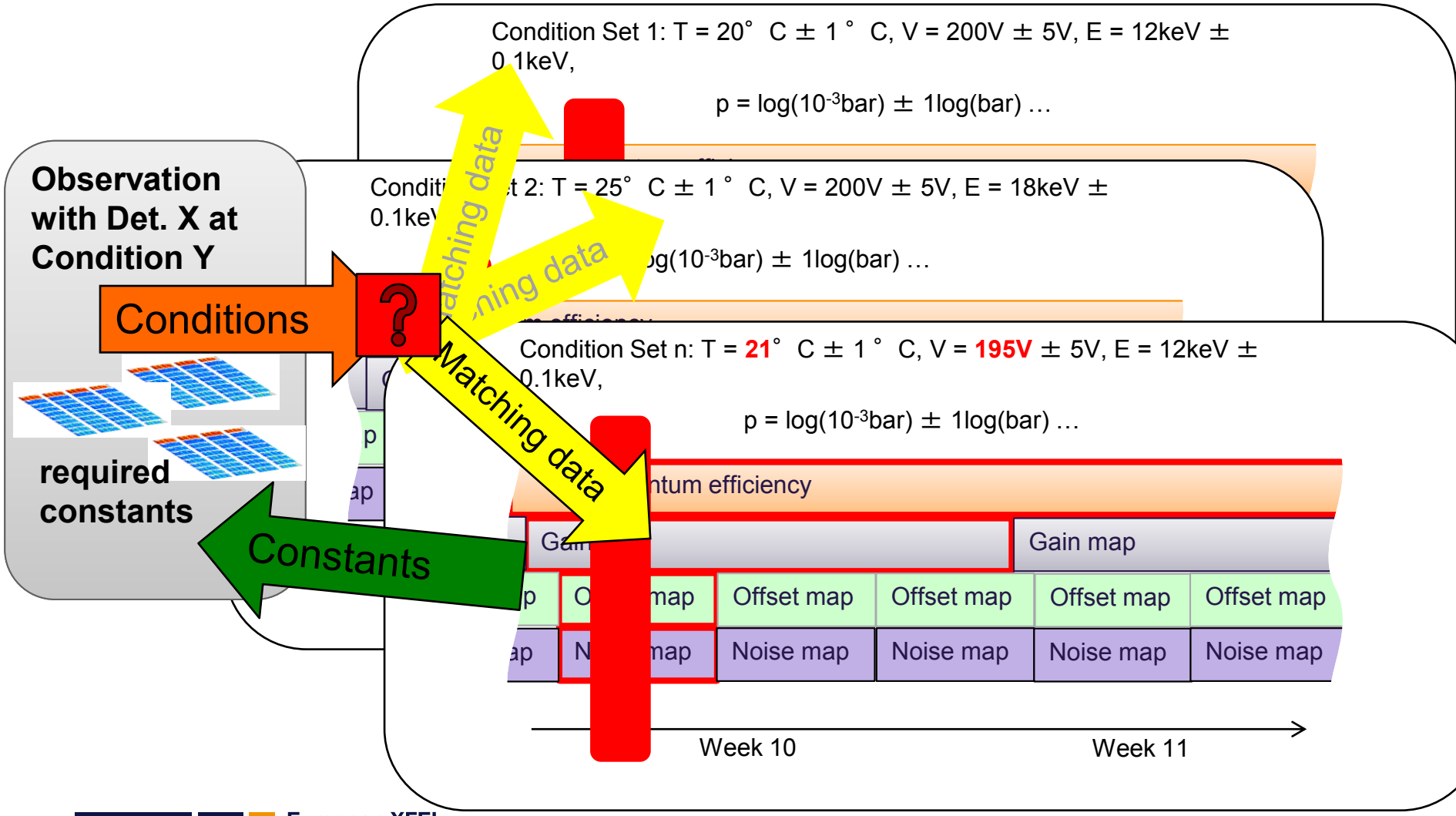
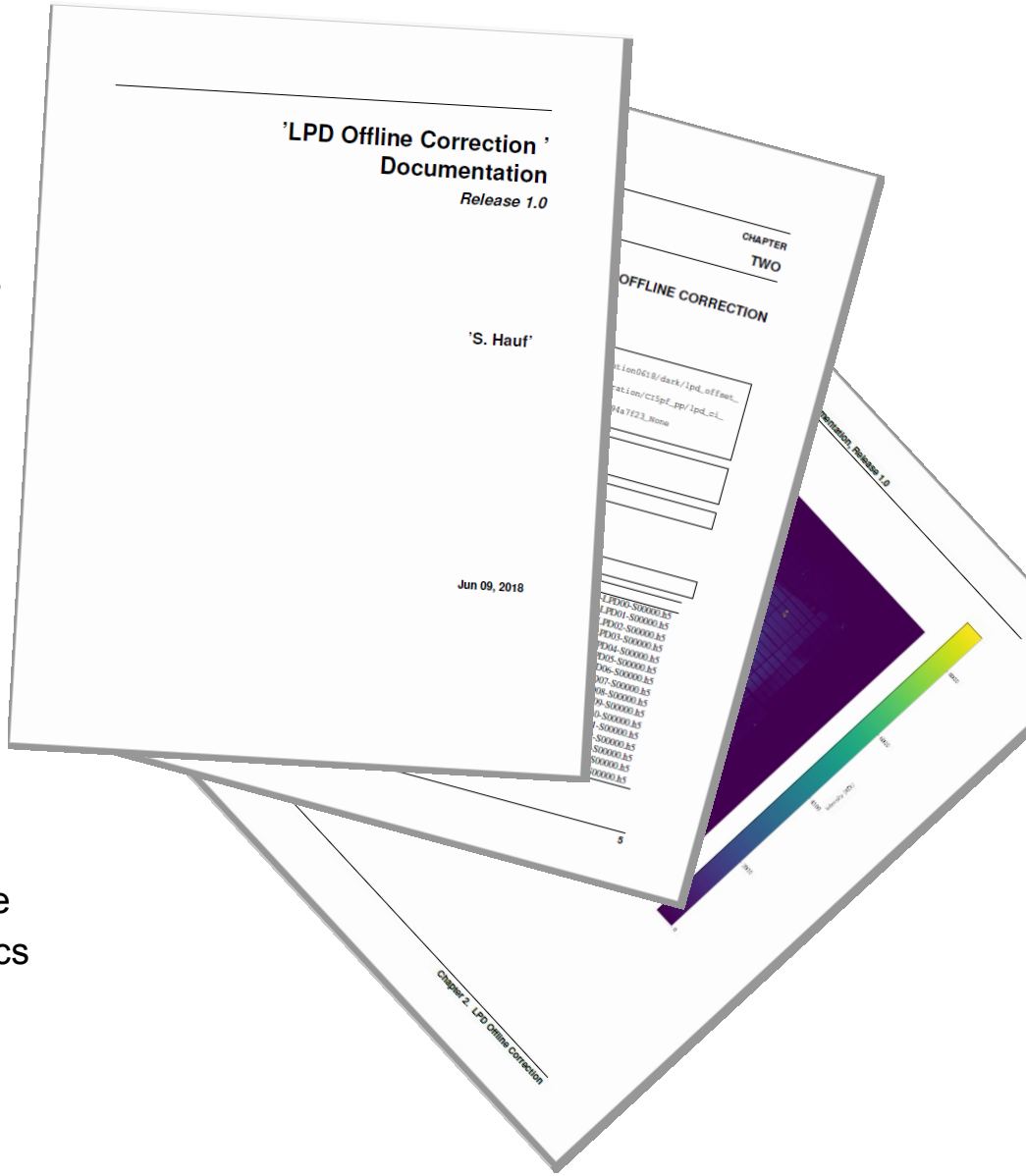
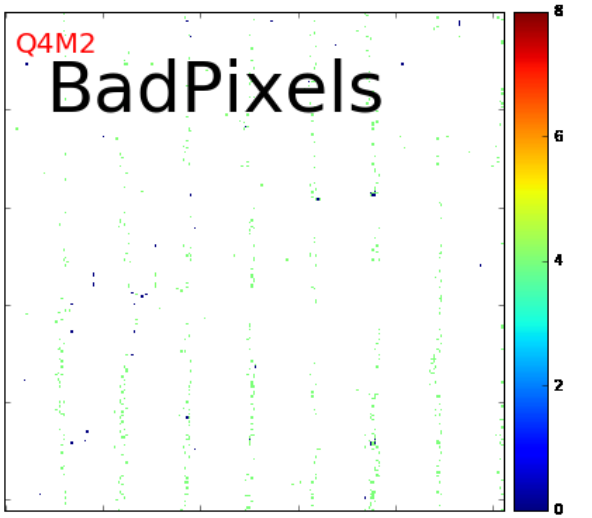


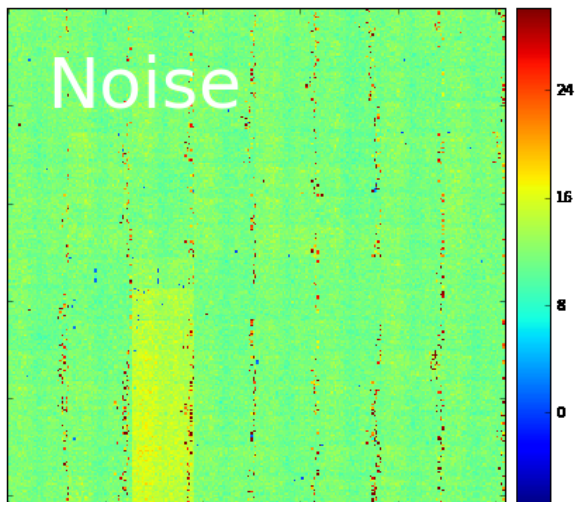
Calibration Report

- A report is generated whenever
  - New calibration data is generated (e.g. dark images)
  - Corrections are applied to raw data
- Contains
  - Information about settings
  - Parameters for offset, noise etc. per supermodule
  - Single shot preview
  - Averaged preview images
  - Map of (max) gain values reached
  - …
- Information about steps how constants are generated are documented via readthedocs and accessible to users

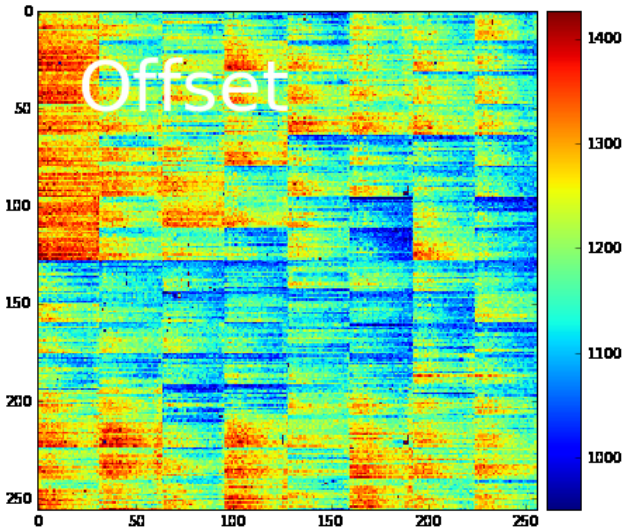


Detector Offset and Noise





Noise (ADU)	100x, 5pF	10x, 5pF	1x, 5pF
Q1M1	11.81	3.71	2.51
Q1M2	11.72	3.69	2.5
Q1M3	17.23	7.24	2.42
Q1M4	11.73	3.74	2.54
Q2M1	15.25	9.88	8.34
Q2M3	11.7	3.71	2.51
Q2M4	12.09	3.78	2.52
Q3M2	12.98	6.19	4.69
Q3M3	18.02	11.17	10.39
Q3M4	11.72	3.69	2.53
Q4M1	30.26	20.97	21.39
Q4M2	18.21	4.61	2.65
Q4M3	11.63	3.69	2.52
Q4M4	11.67	3.7	2.53

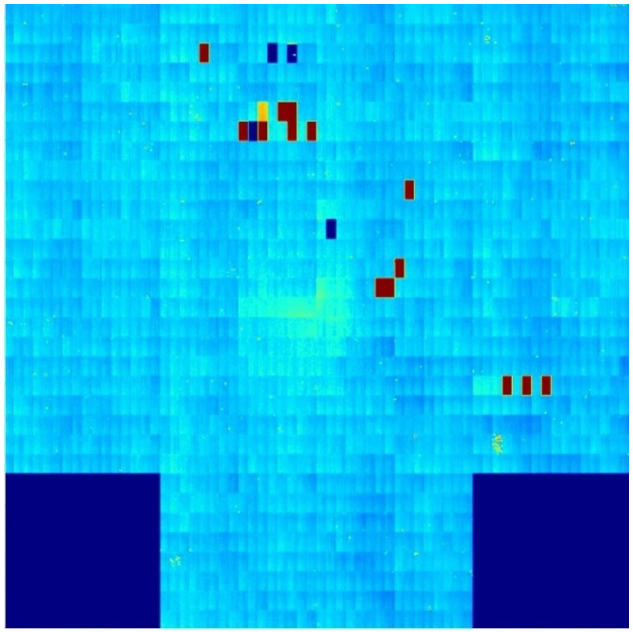


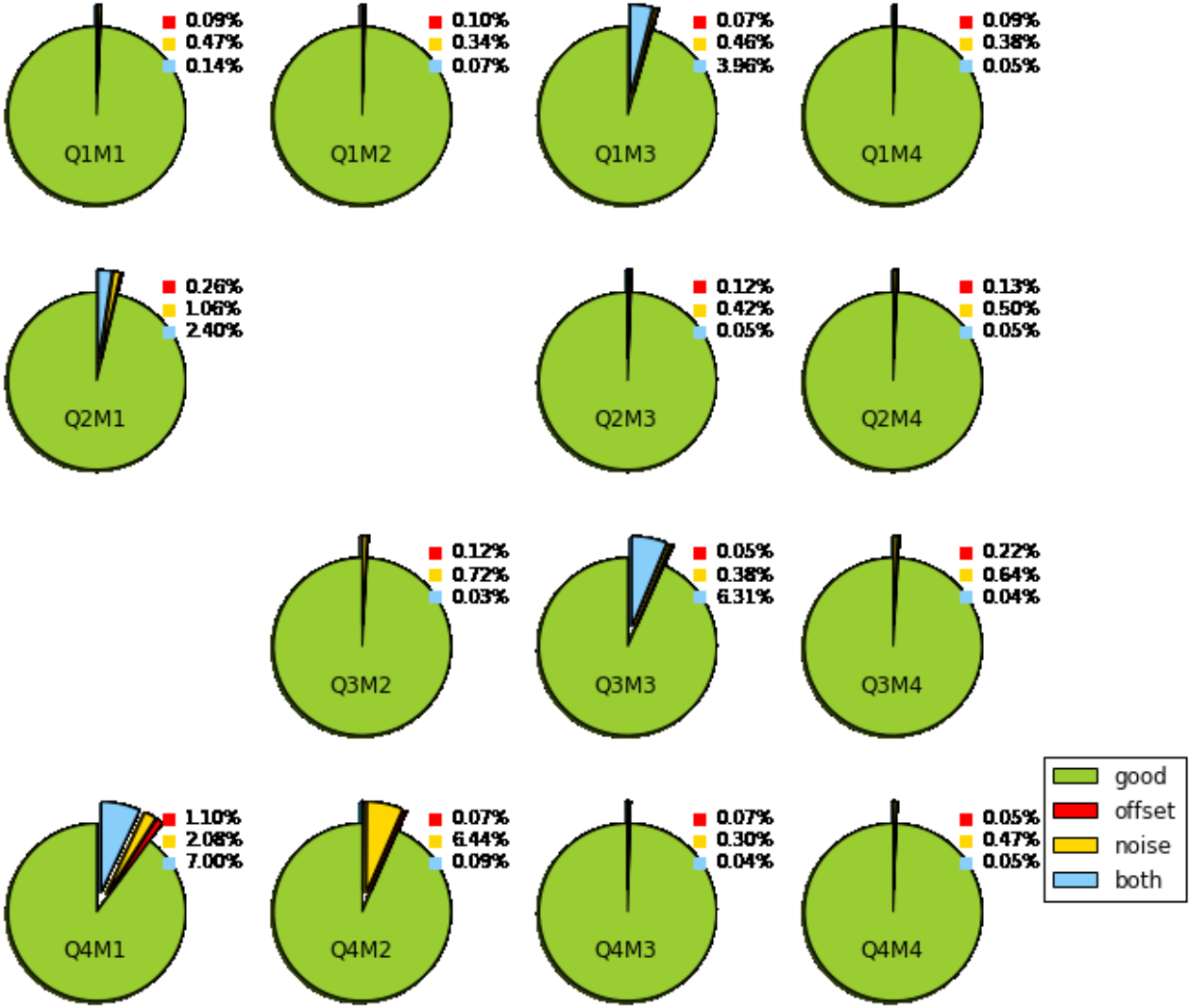
- Offsets are acquired using a Karabo middle-layer device, automatically switching detector configuration, state and DAQ
- Offset and noise deduced for each module
  - Pixels flagged as bad if certain thresholds are exceeded

Dark Image Deduced Bad Pixels – High Gain

- bad pixels are pixels that:
  - exceed offset thresholds
  - exceed noise thresholds

- most modules have less than 1% bad pixels
  - exception: Q1M3,Q3M3, Q4M1

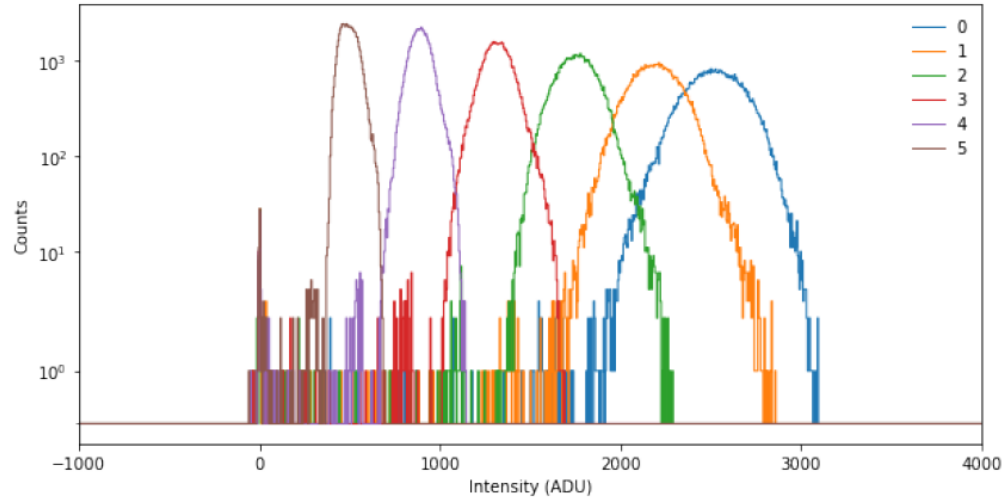




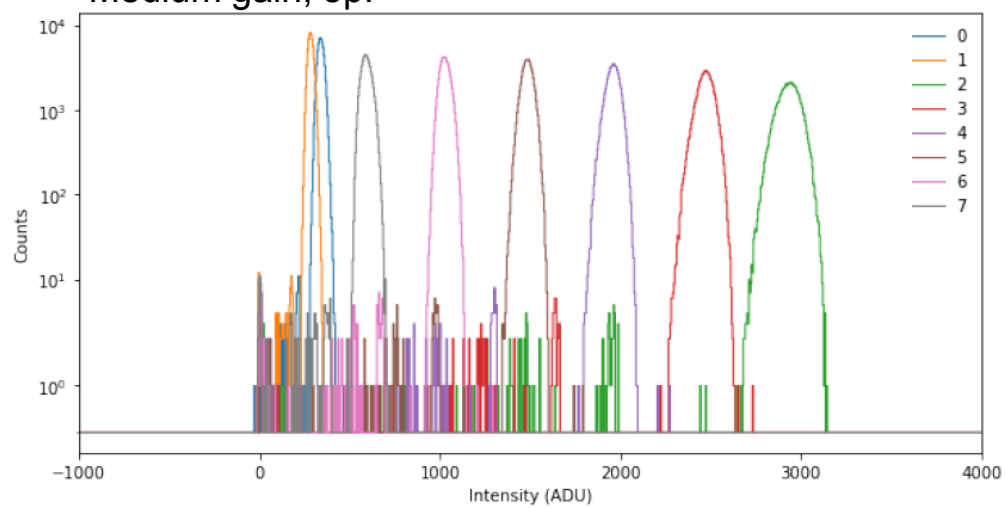
Gain Evaluation

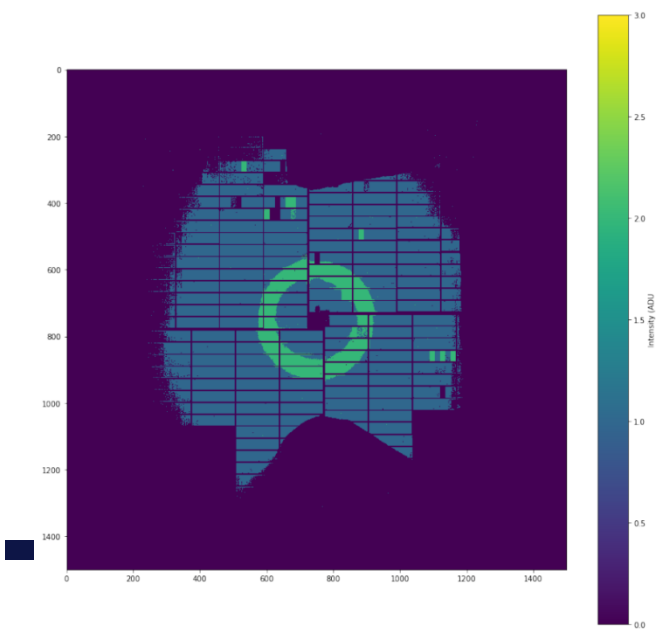
- Internal charge injection circuit allows a scan over a good part of the dynamic range
- Overlap allows conversion between gain stages
- On-memory-cell correction, pixel/supermodule correction done with flat field in a second step

High gain, 5pF



Medium gain, 5pF





← Example of a gain bit map in a liquid scattering experiment

Performance

- Assuming standard operating conditions
  - Bias voltage of 250V
  - 15 °C cooling temperature
  - Full speed (4.5 MHz, <100ns integration time)
  - Typically running at 1.1 MHz, skipping 3 images, 30 pulses per train

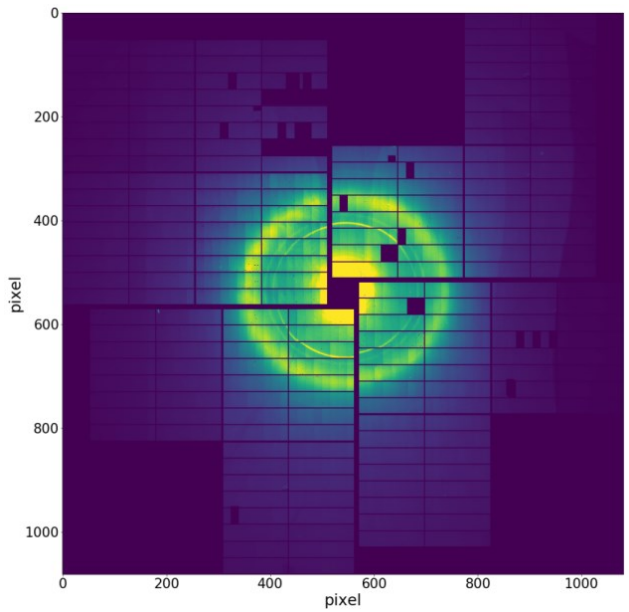
Experiment/ Proposal	Number of Hours	Raw data amount [TB]
p2016	100	8.5
p2026	60	28
p2045	60	40
p2050	60	27
p2052	120	34.9
p2072	60	20
p2073	120	18.3
Total	**588h**	**176.7 TB**

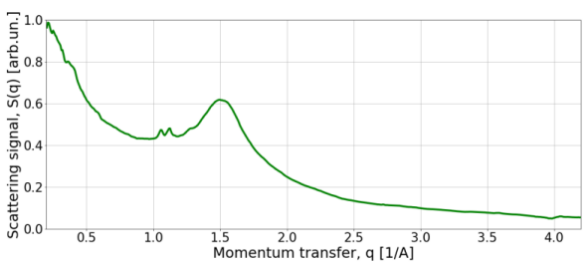
Some performance parameters (Day-1)	
Noise	0.35 photons @ 12keV (1200 e^-)
Temporal cross-talk * (in following frame)	< 4%
Spatial cross-talk (in neighbouring pixels)	< 2%
Deviation from linearity	< 5%
Bad pixels	< 1%
Relative gain variation (pixel-to-pixel)	< 5%
Memory Droop	< 2%
Radiation Hardness	up to 5 MGy

PRELIMINARY

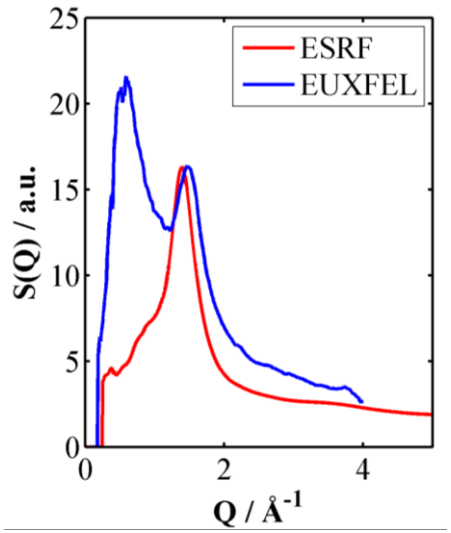
* Measured on pixel level, not taking into account high occupancy effects

An example from user operation



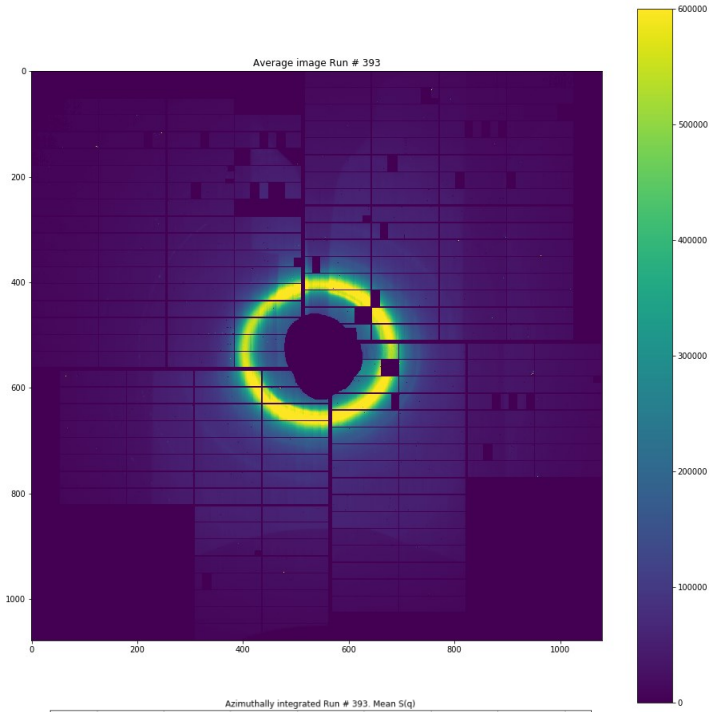


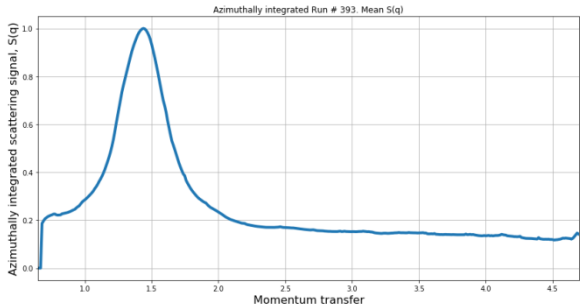
- Pump-probe Scattering on Cu-complex solution in THF (Experiment #2052)
- 30 bunches/train, 9.3 keV, ~100uJ/pulse, focused to ~20 um
- Optical excitation: TH of Tangerine (343 nm)
- Liquid scattering with LPD, XES with Gotthard



Courtsey of Grigory Smolentsev (PSI), M. Laursen and K. Haldrup (DTU)

An example from user operation





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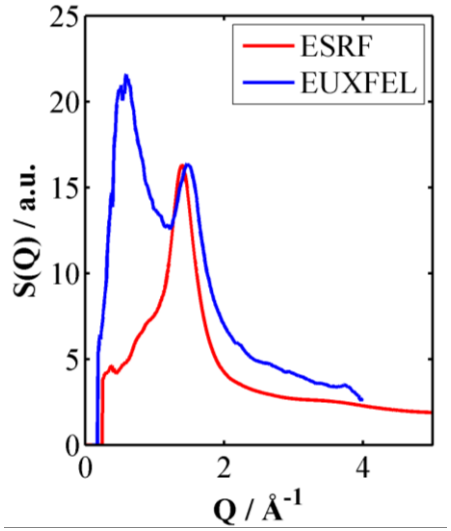

Courtsey of Grigory Smolentsev (PSI), M. Laursen and K. Haldrup (DTU)

Summary and Outlook

- The LPD 1M detector is successfully in operation at the FXE instrument of the European XFEL
- First calibration data exists
- Routines are established and in use by instruments and users, reports are generated automatically
- Large amounts of data already taken and under analysis by users

But there is also room for improvement …

- Evaluate single photon peaks once accelerator provides X-ray energies above ~14keV → confirm conversion factors
- New firmware under preparation with more flexible timing and gain switching options
- More detailed study of 50pF mode and maximum dynamic range

Thanks to:

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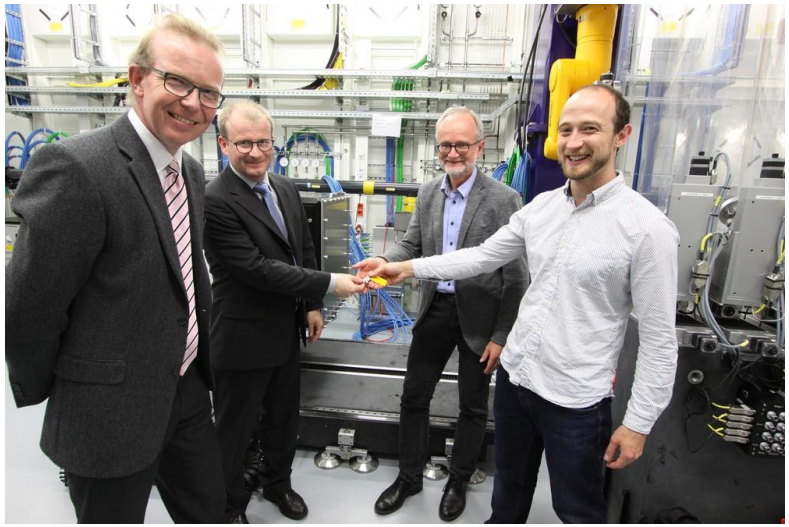

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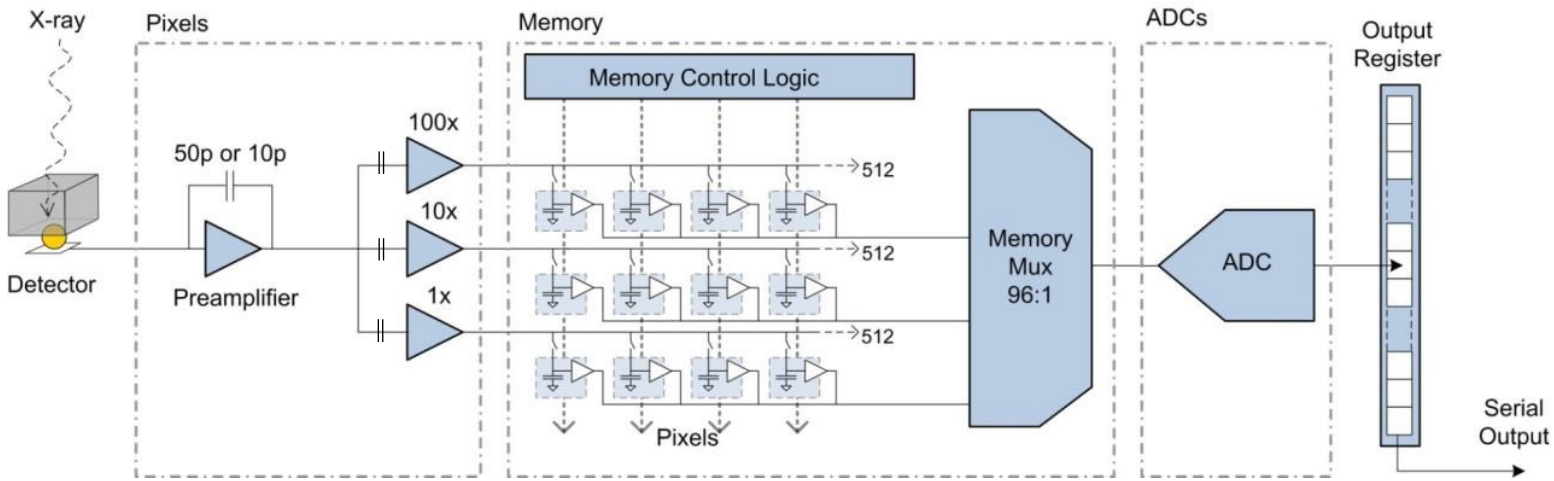
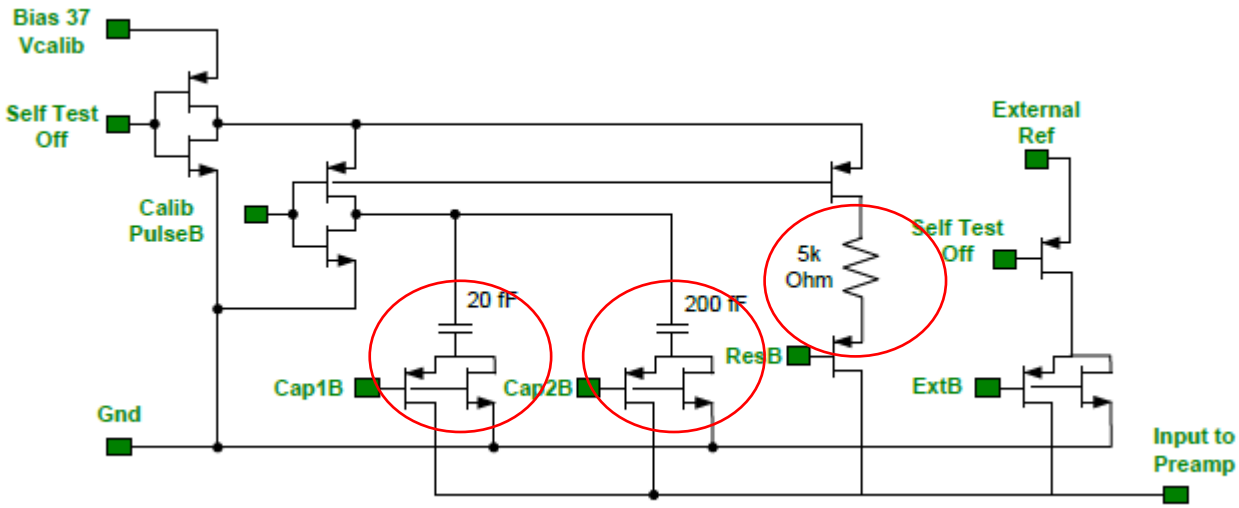
Backup Slides

Architecture



- Pixelated Silicon Sensor
- ASIC (8 per sensor)
  - Integrating preamplifier with 2 dynamic range options (50 pF or 5 pF)
  - 3 parallel gain stages to cover dynamic range
  - Analogue memory (512 frames)
  - On-chip ADCs (16)
- Custom DAQ board (FEM) reads out 16 sensor modules

Charge Injection Circuit



Several ways of charge injection:

- 20fF capacitor → high gain
- 200fF capacitor → medium gain
- Resistor → low gain

(with overlaps)